

Standard Model Higgs Searches at the Tevatron

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on behalf of the CDF and DØ collaborations

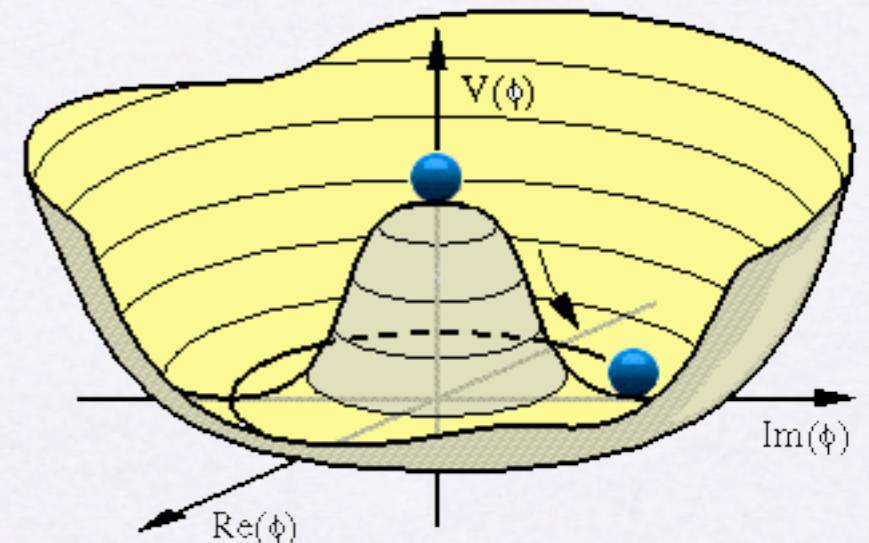
SM Higgs in a Nutshell

In the Standard Model, the Higgs field is a complex scalar field, $V(\phi)$

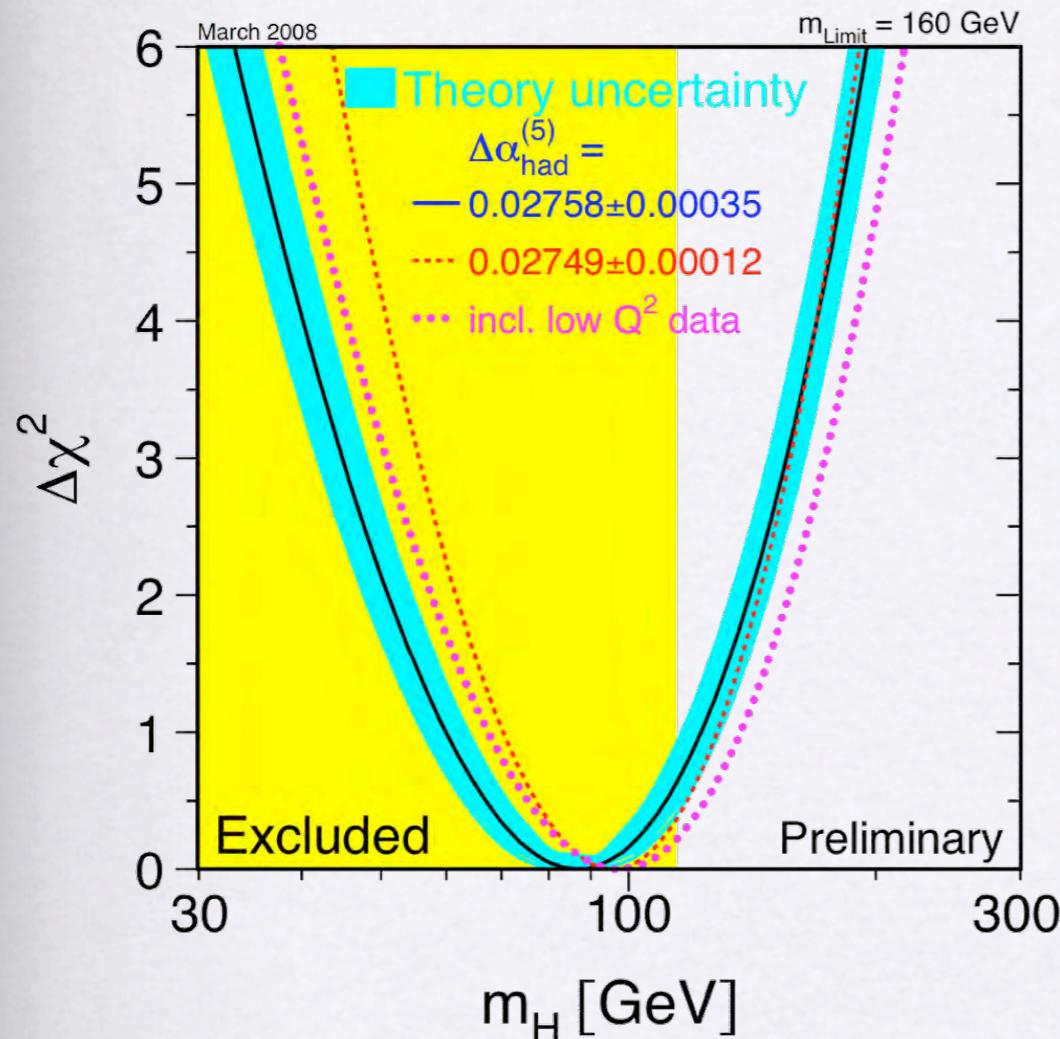
Through electroweak symmetry breaking, the gauge bosons W^\pm and Z acquire mass

A single Higgs boson with spin 0 appears

The only free parameter is its mass



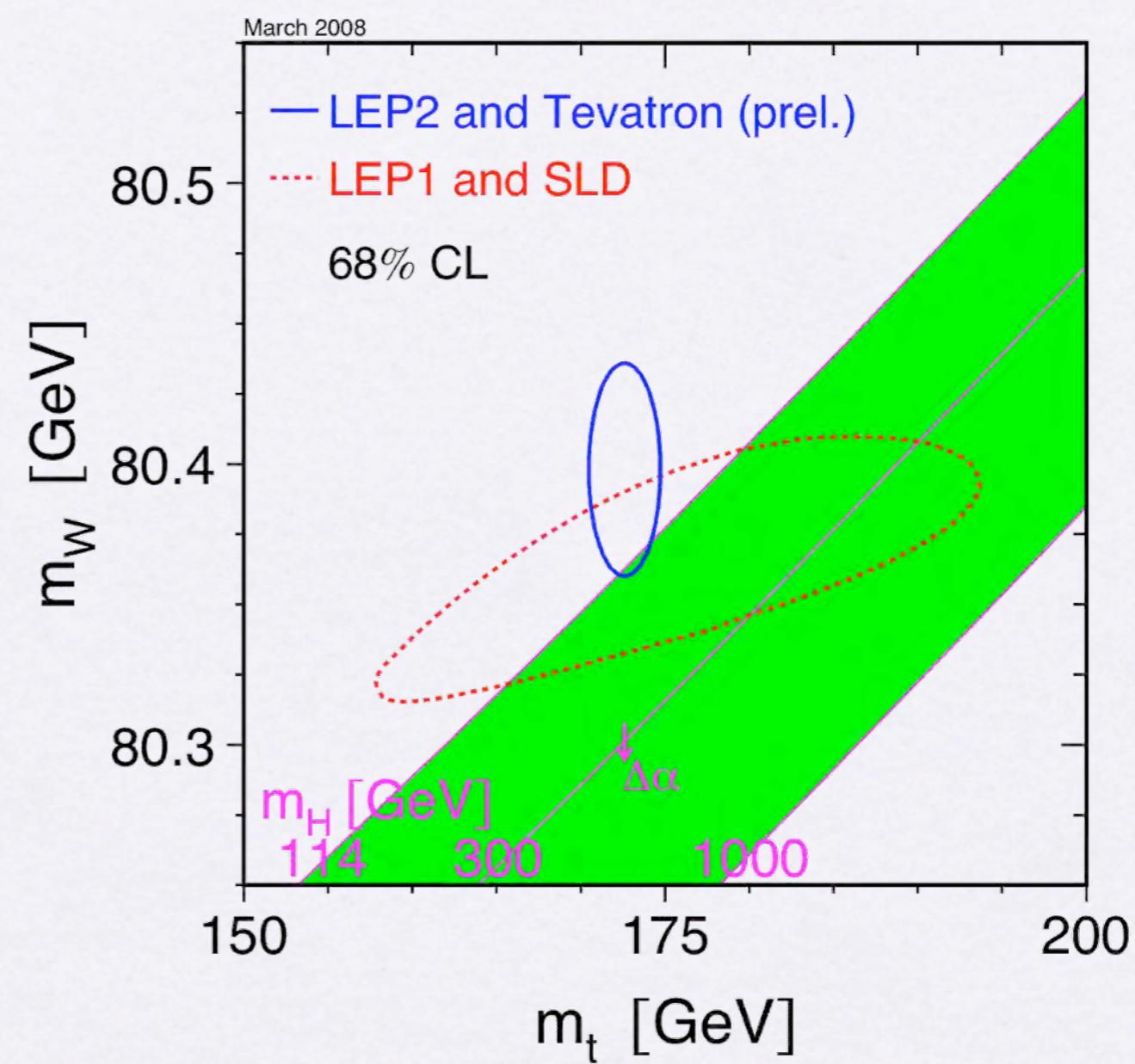
Stalking the Higgs



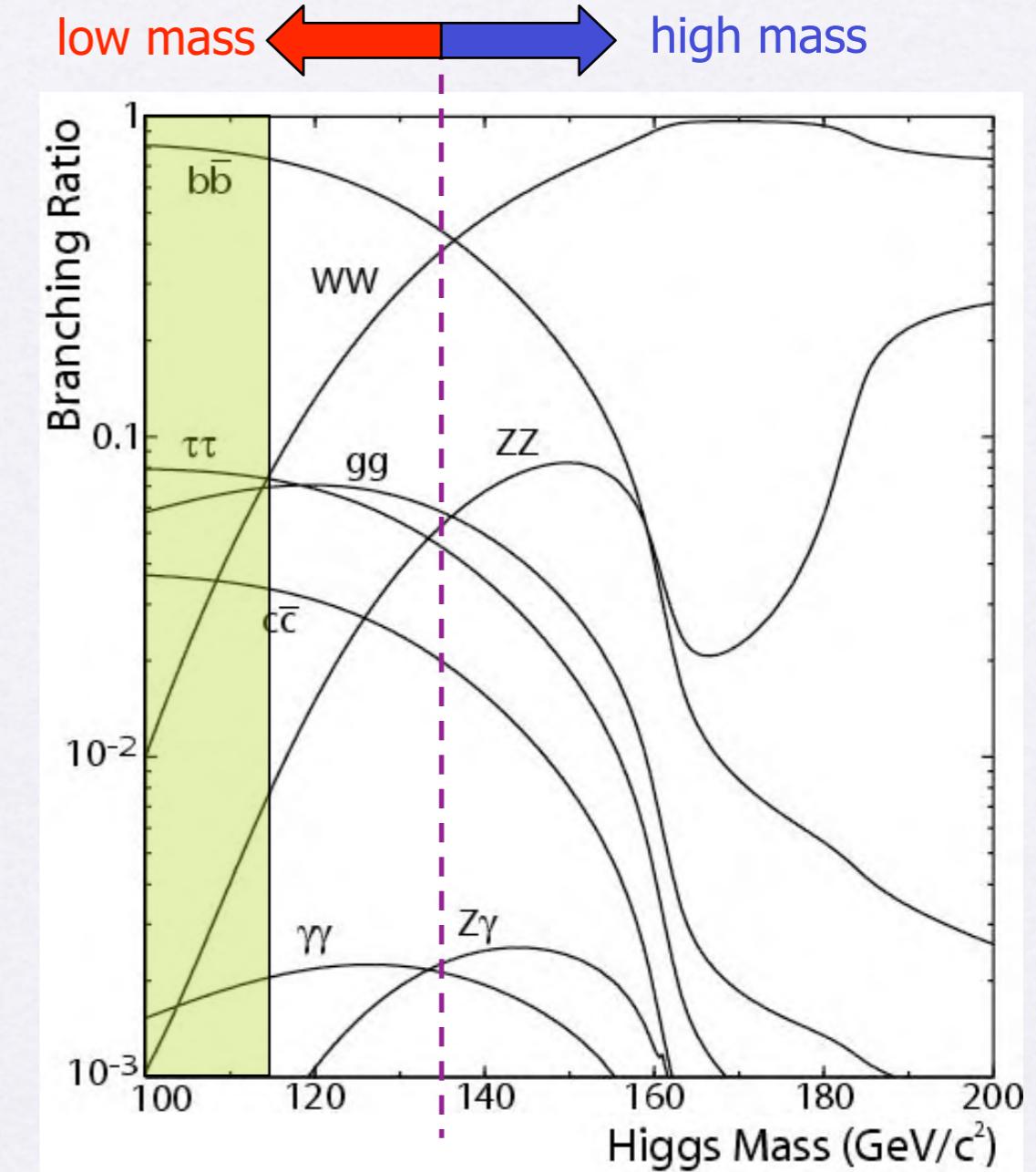
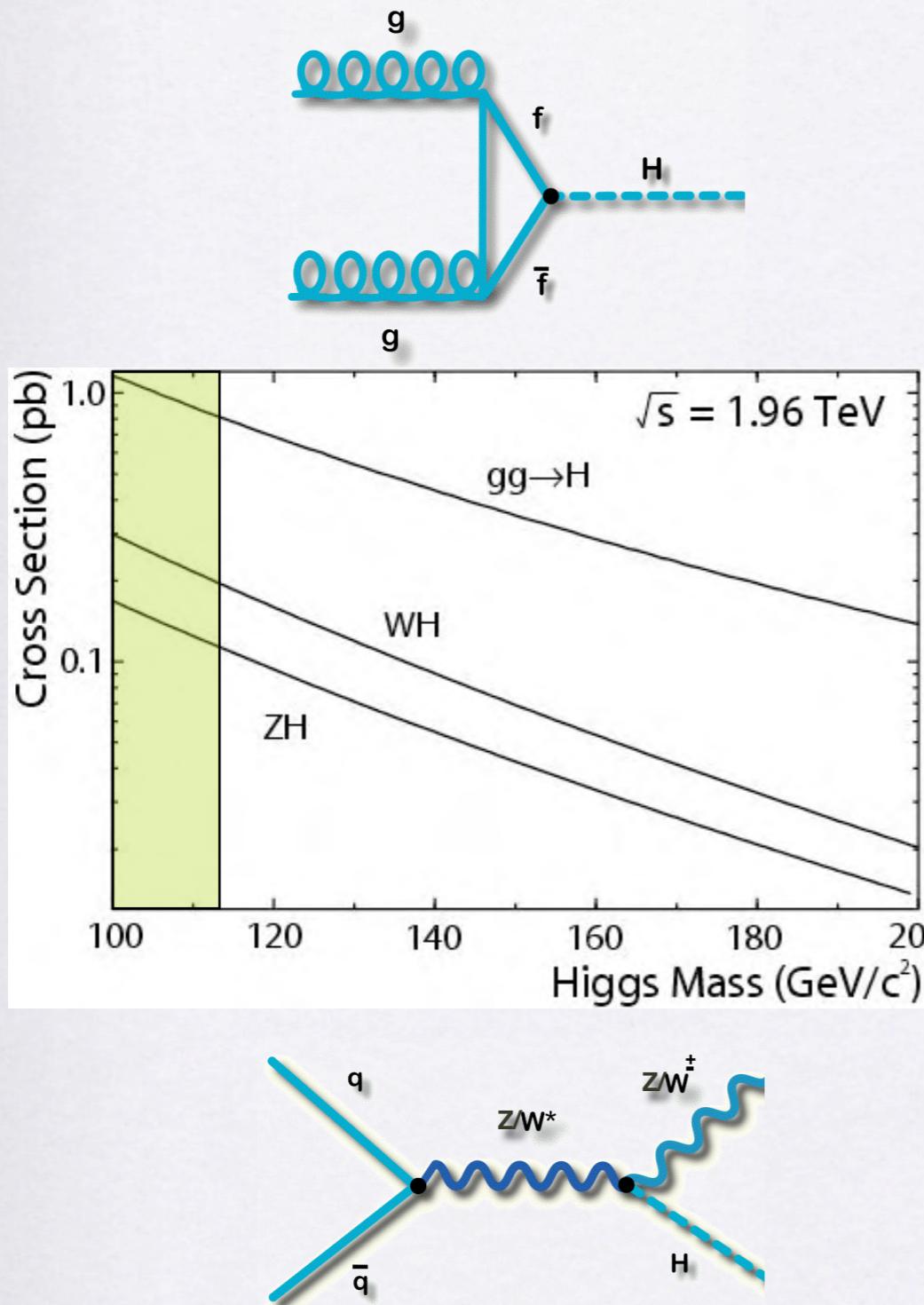
EW data indirect constraint
(Winter 2008)

- $m_H = 87^{+36}_{-27} \text{ GeV}$
- $m_H < 160 \text{ GeV}$ (95% CL)
- $m_H < 190 \text{ GeV}$ w/ LEP II limit

LEP direct searches:
 $m_H \geq 114.4 \text{ GeV}$ @ 95% CL



Higgs at the Tevatron



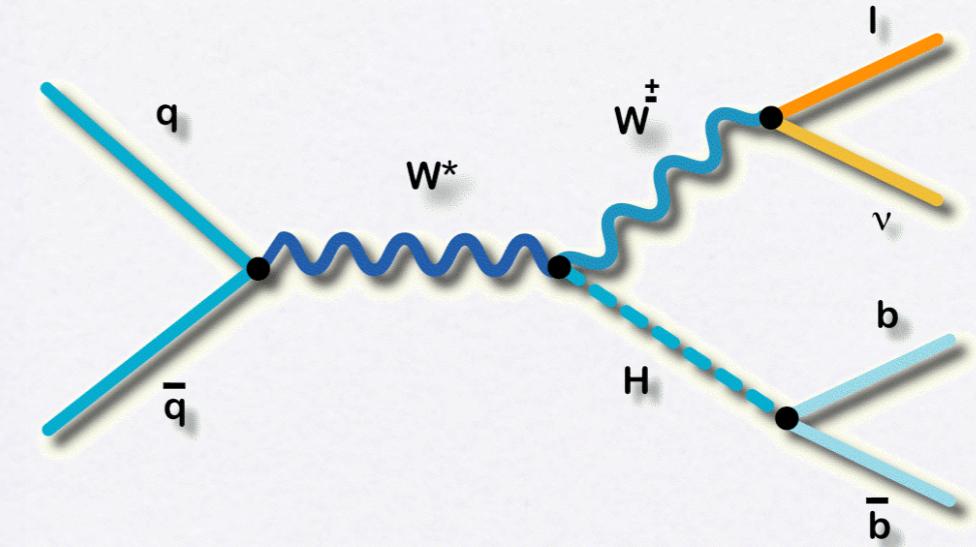
SM Higgs Searches

- $W H \rightarrow e/\mu\nu + bb$
 - high p_T isolated lepton, missing E_T , two b-jets
- $Z H \rightarrow ee/\mu\mu + bb$
 - two high p_T isolated leptons with Z invariant mass, two b-jets
- $Z H \rightarrow \nu\nu + bb$
 - high missing E_T and two b-jets
- $H \rightarrow \tau\tau$
 - two taus, two jets
- $H \rightarrow \gamma\gamma$
 - two isolated photons
- $H \rightarrow WW^* \rightarrow \ell\nu\ell'\nu'$
 - two high p_T isolated leptons, missing E_T , no jets

$W H \rightarrow e/\mu \nu b\bar{b}$

Selection

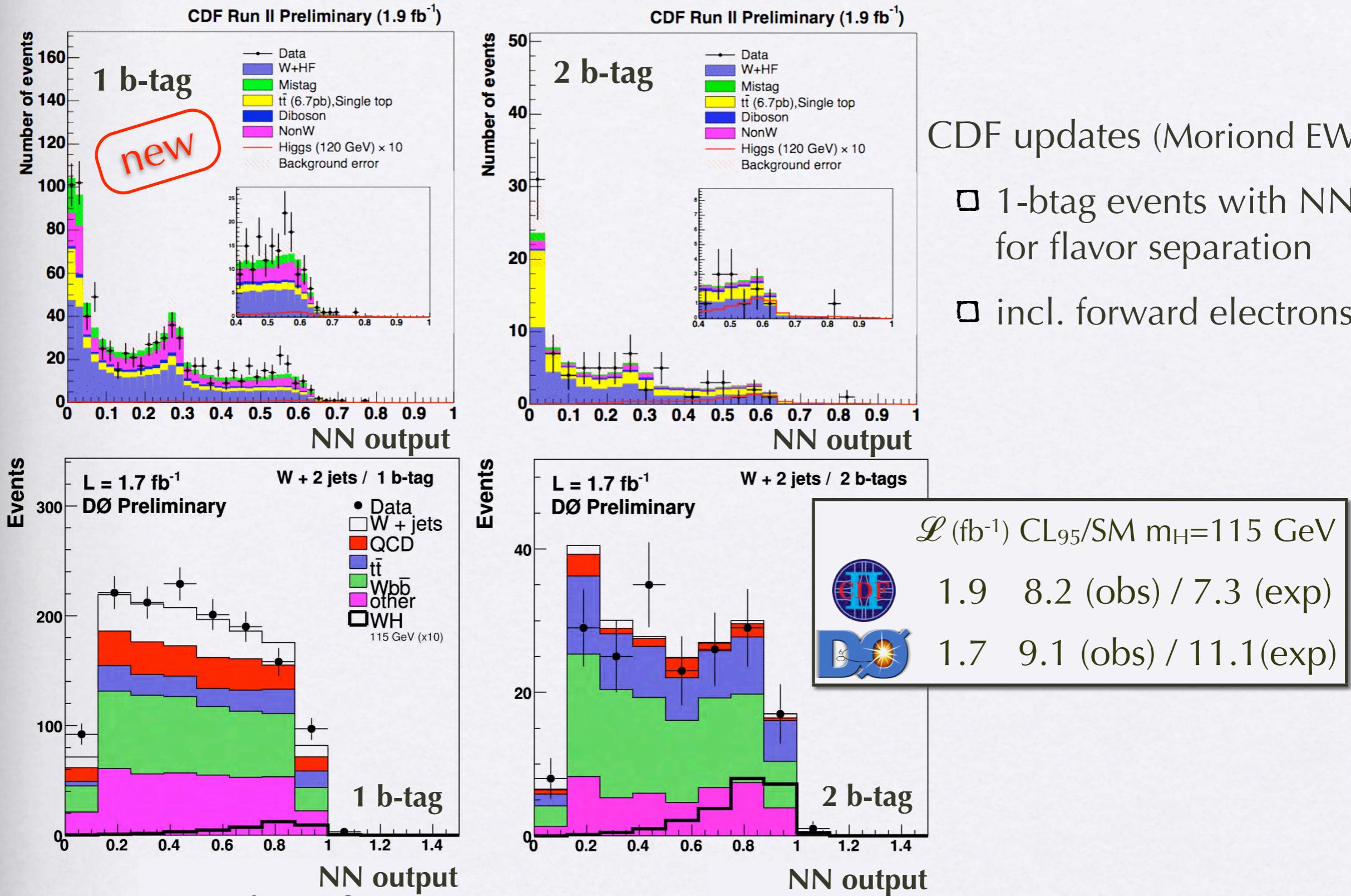
- lepton id & p_T
- missing $E_T > 20 \text{ GeV}$
- 2 jets with 1 or 2 b-tags
- Neural Net (NN) to separate background from signal



Backgrounds

- $W + b\bar{b}$ is non-reducible, but non-resonant
→ good dijet invariant mass resolution
- $t\bar{t}$ → $\ell + \text{jets}$: top is heavy
→ look at sum of energies of objects in the event
- multijets: difficult to model
→ taken from data

WH \rightarrow e/ μ v bb



ZH \rightarrow ee/ $\mu\mu$ bb

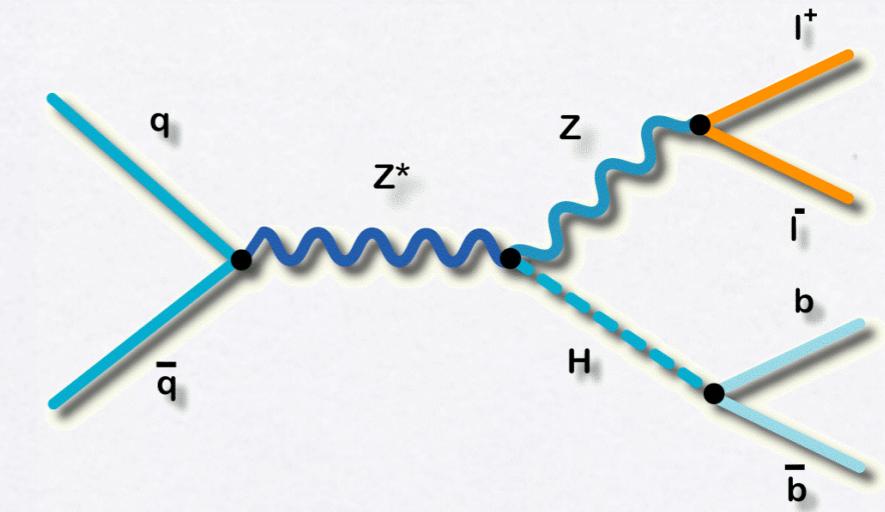
Less sensitive than WH

$$\square \sigma_{ZH} < \sigma_{WH} / \text{Br}(Z \rightarrow \ell^+ \ell^-) < \text{Br}(W \rightarrow \ell^+ \nu)$$

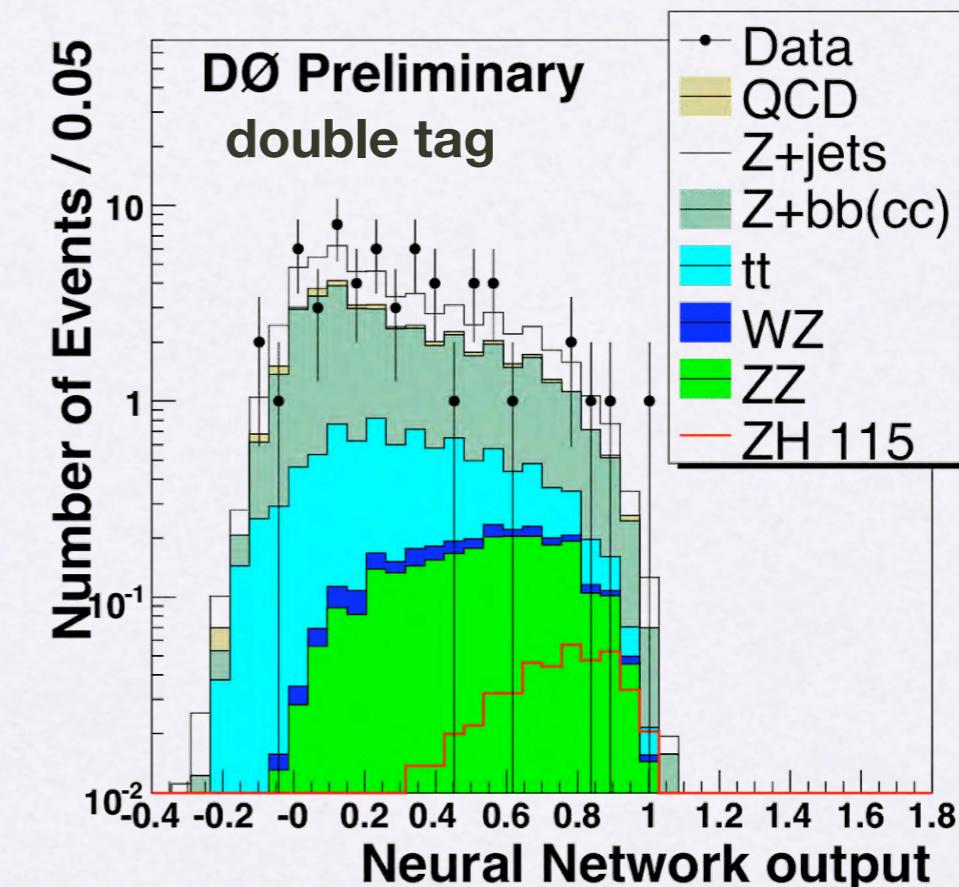
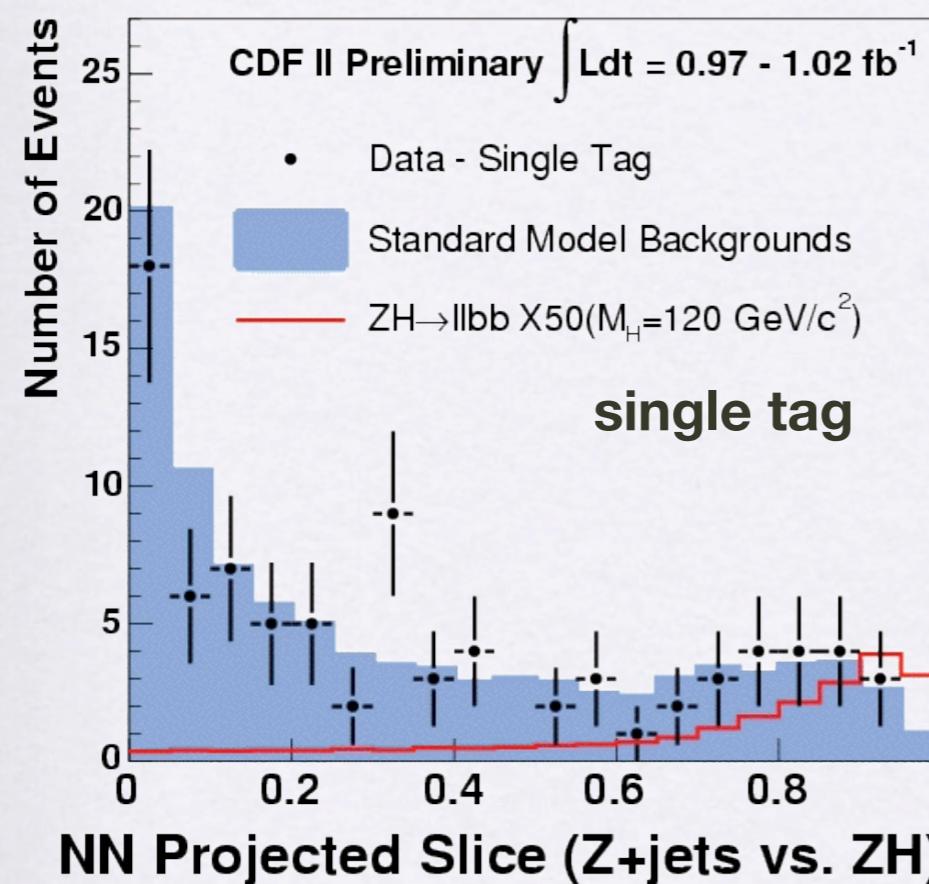
$Z \rightarrow \ell^+ \ell^-$ provides a nice handle

Single & double b-tagged sample

1-dim (DØ) or 2-dim (CDF) Neural Net



\mathcal{L} (fb $^{-1}$) CL ₉₅ /SM m _H =115 GeV		
	1.0	16 (obs) / 16 (exp)
	1.1	18 (obs) / 20 (exp)



$ZH \rightarrow vv bb$

Larger cross-section & acceptance, but hard

- no visible leptons & only 2 jets in final state

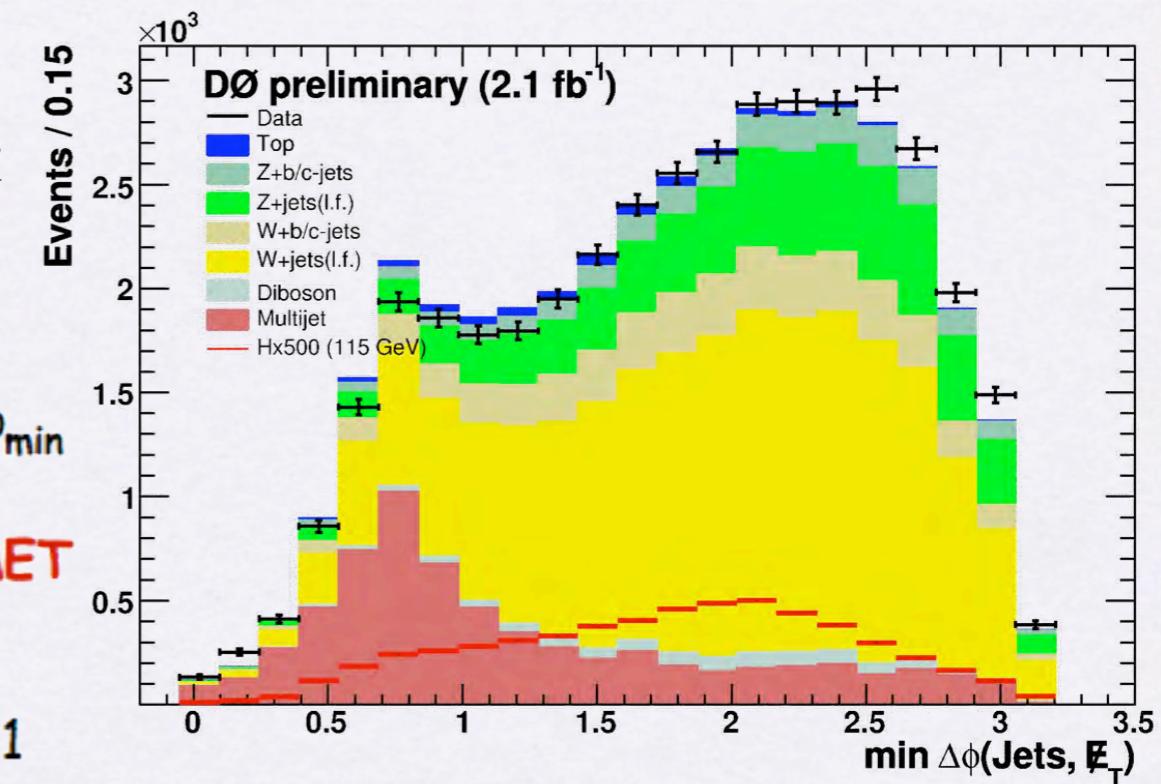
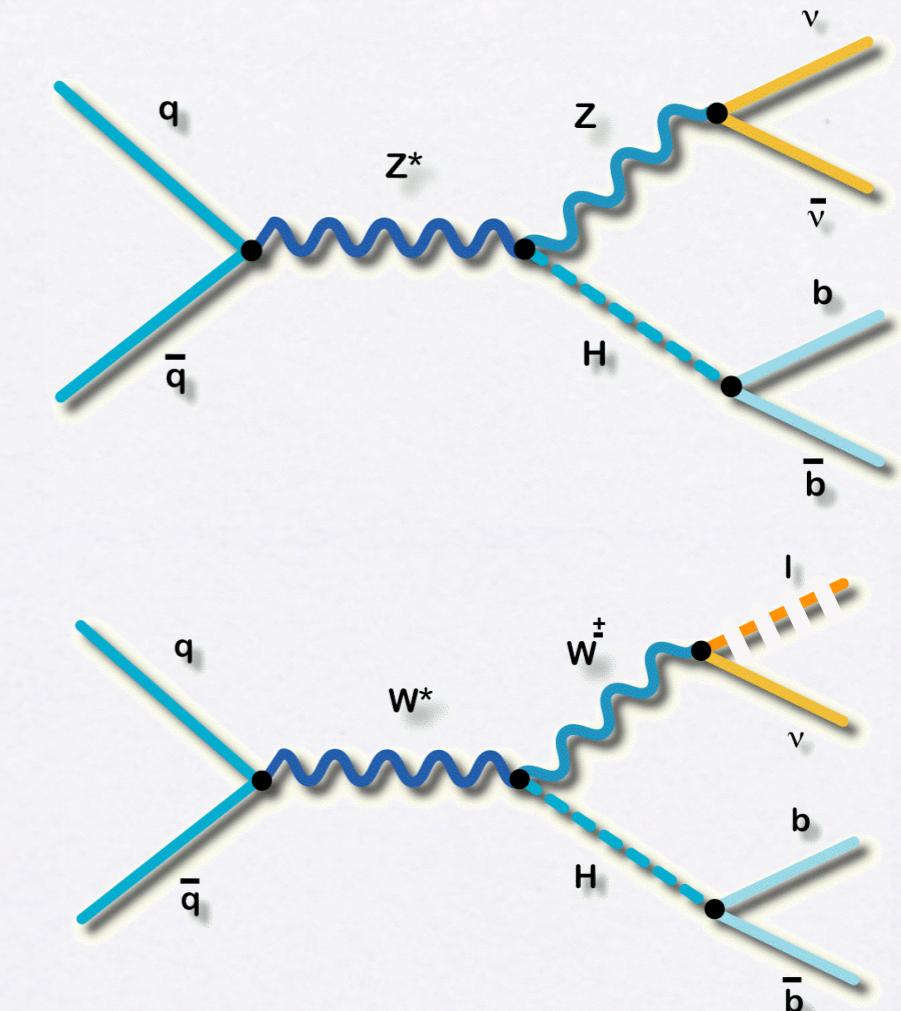
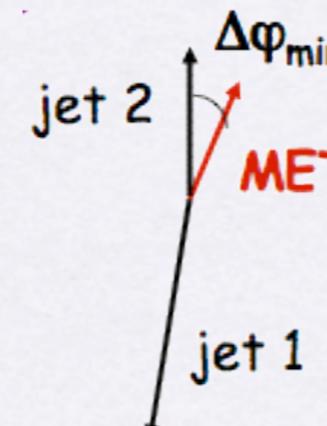
Contribution from WH if ℓ missed

Selection

- missing $E_T > 50$ GeV
- 2 b-tagged jets
- no isolated electrons or muons

Multijet events with heavy flavor content are main background

- difficult to model – derived from data
- CDF uses 1-btag sample
- DØ uses min $\Delta\phi$ between missing E_T and nearest jet

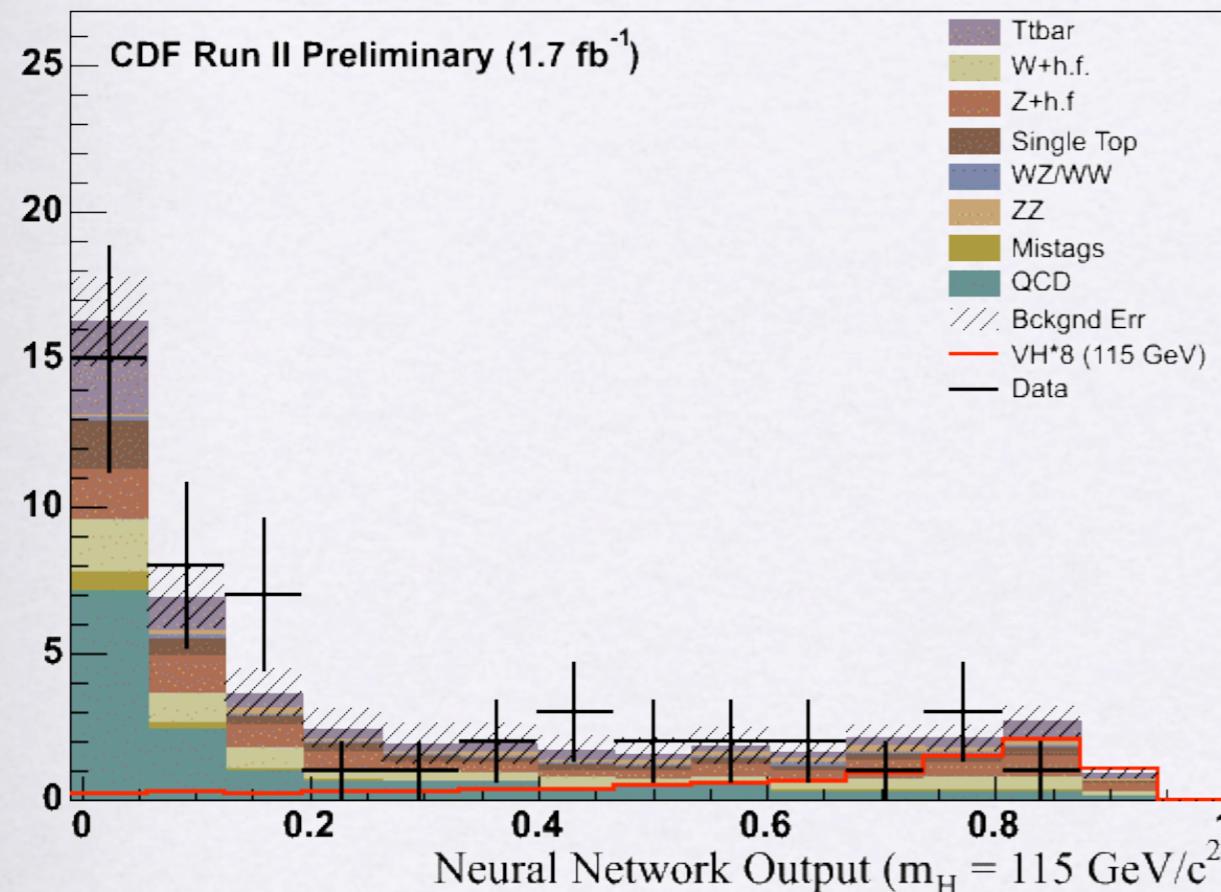


ZH \rightarrow VV bb

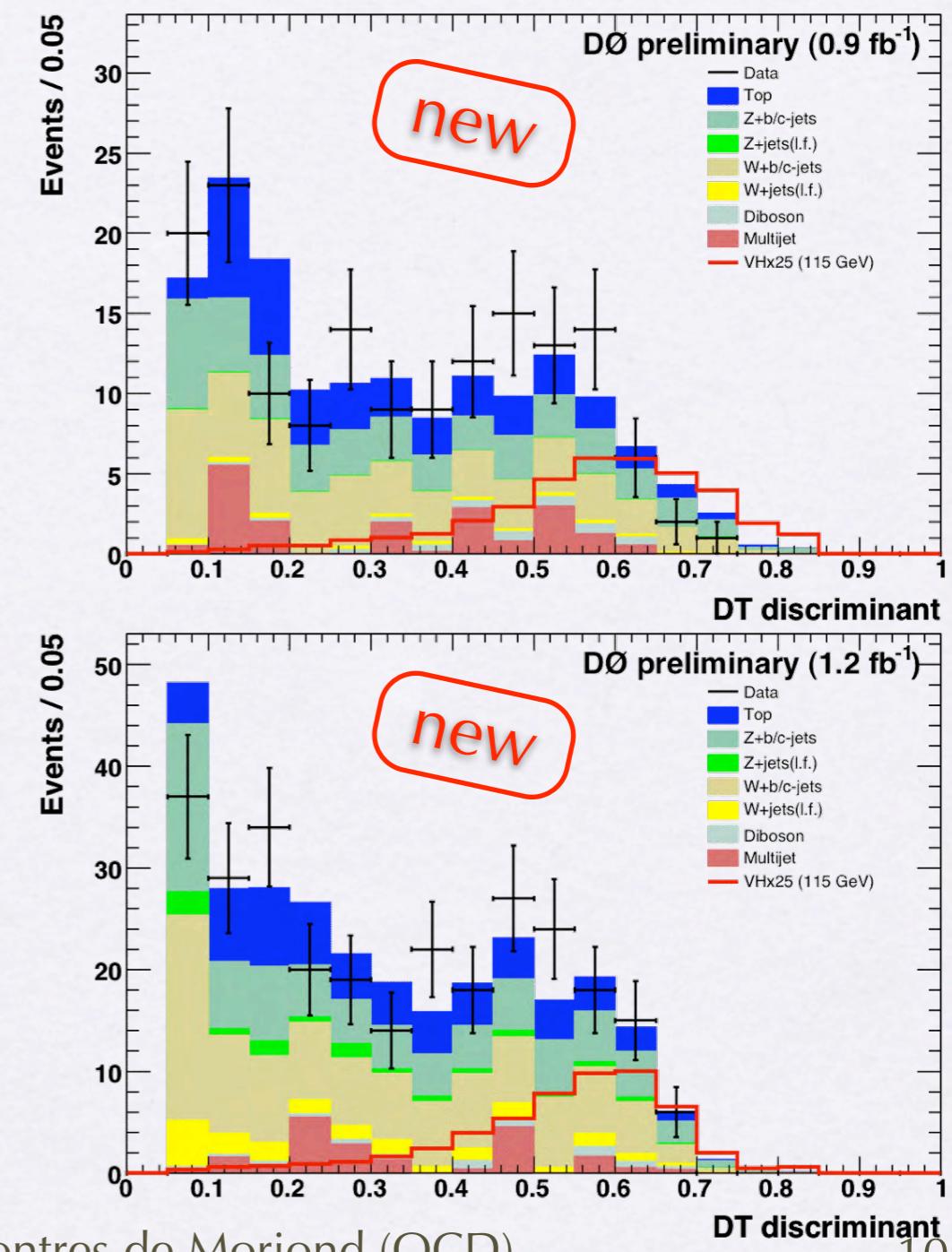
Multivariate techniques

- CDF uses 2 NN
 - o track based missing E_T
 - o calorimeter & tracking information
- D \emptyset uses Boosted Decision Trees (DT)

Double Vertex Tag (Signal Region)



$\mathcal{L} (\text{fb}^{-1}) \text{ CL}_{95}/\text{SM } m_H=115 \text{ GeV}$		
	1.7	8.0 (obs) / 8.3 (exp)
	2.1	7.5 (obs) / 8.4 (exp)



$H \rightarrow \tau\tau$

new

Hard due to small BR (10% of $H \rightarrow bb$)

- simultaneous search for WH , ZH , vector boson fusion, and ggH

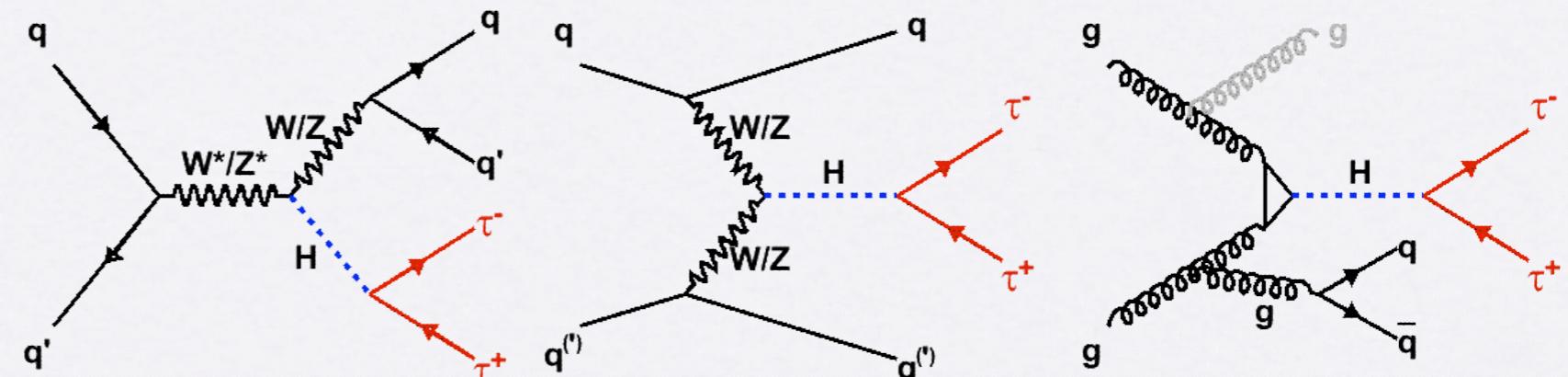
- benefit from high branching ratio of $W/Z \rightarrow 2$ jets

$\tau_{\text{lep}} \tau_{\text{had}}$ mode

- lepton $p_T > 10$ GeV
- $\tau_{\text{had}} p_T > 15$ GeV

Select minimum of 3 NN discriminants

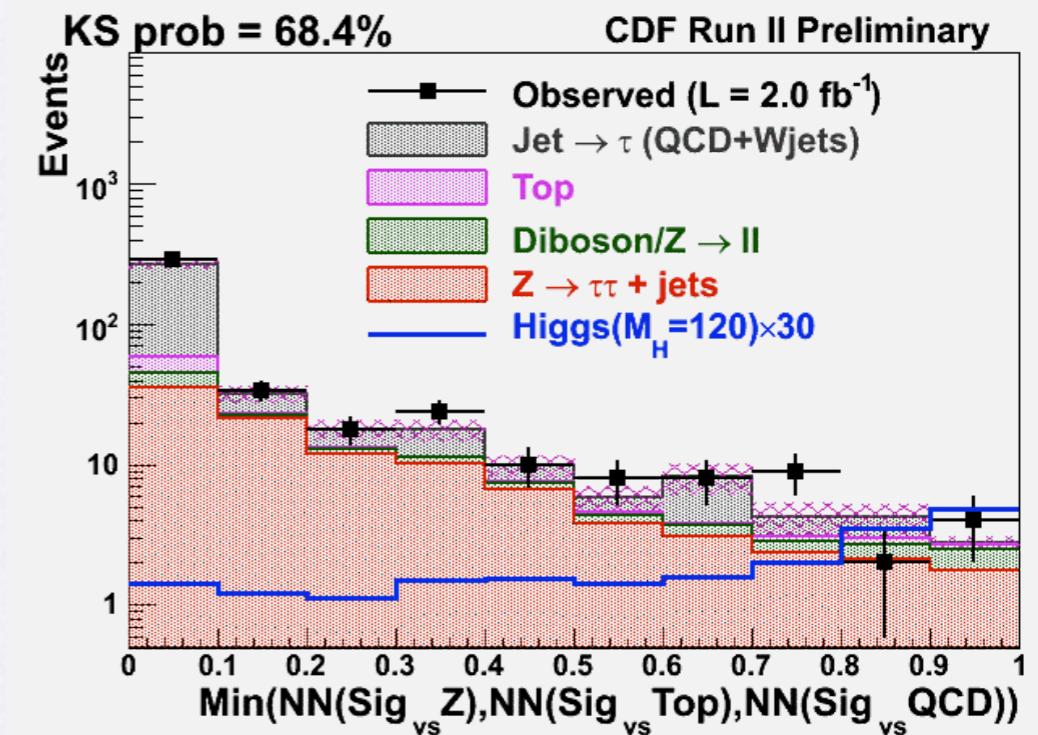
- signal vs $Z \rightarrow \tau\tau + \text{jets}$
- signal vs $t\bar{t}$
- signal vs QCD



$\mathcal{L} (\text{fb}^{-1}) \text{ CL}_{95}/\text{SM } m_H = 120 \text{ GeV}$



2.0 30 (obs) / 24 (exp)



$H \rightarrow \gamma\gamma$

new

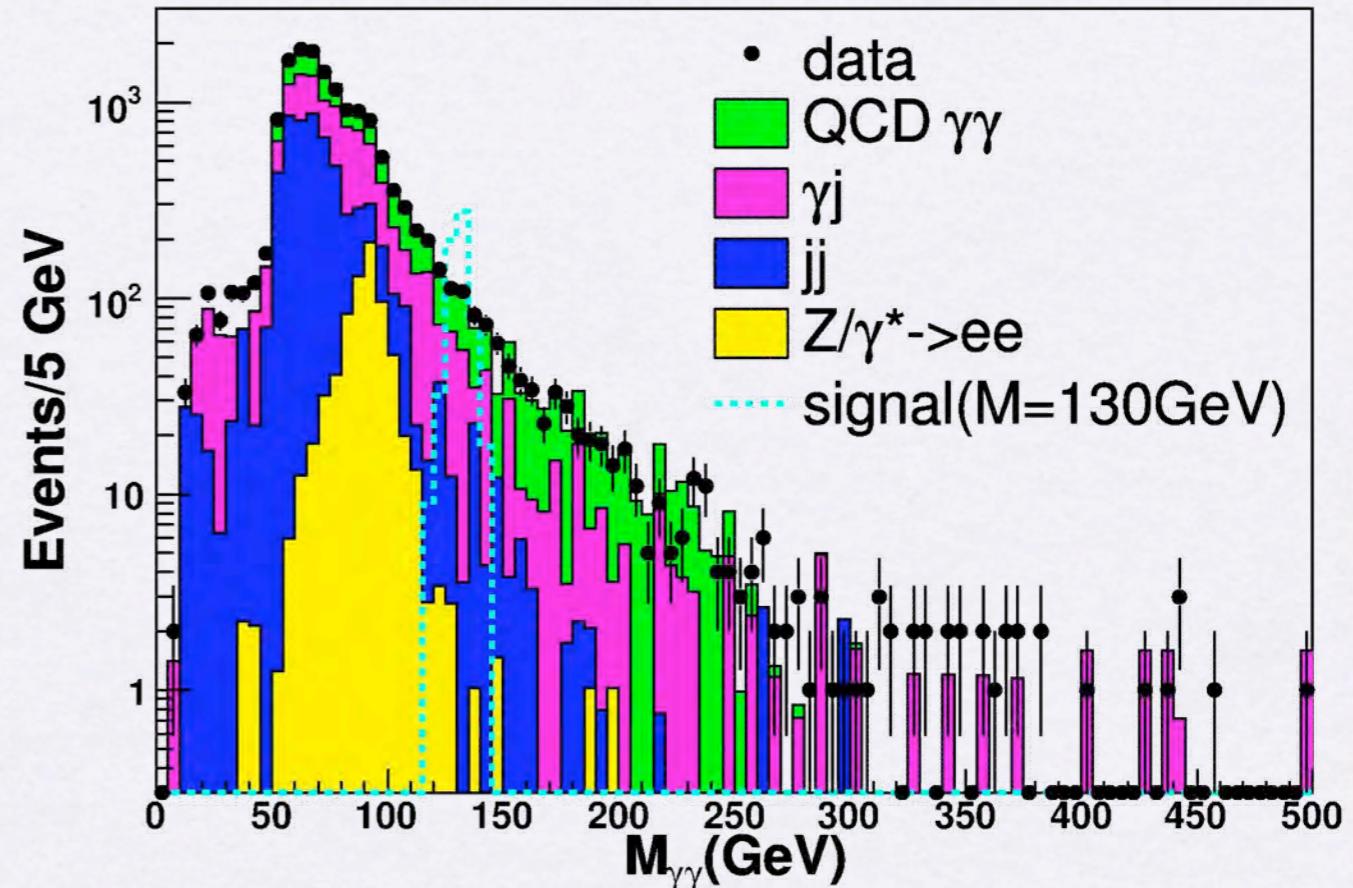
Selection

- 2 isolated photons with $E_T > 25$ GeV
- examine invariant mass spectrum



Main backgrounds

- Drell-Yan events with both electrons misidentified as photons
- direct QCD di-photon events
- $\gamma + \text{jets}$ and jet+jet events
 - QCD jet fakes estimated using the shower-shape correlations between the 2 photons ("matrix method")



$$H \rightarrow WW^* \rightarrow \ell\nu \ell'\nu'$$

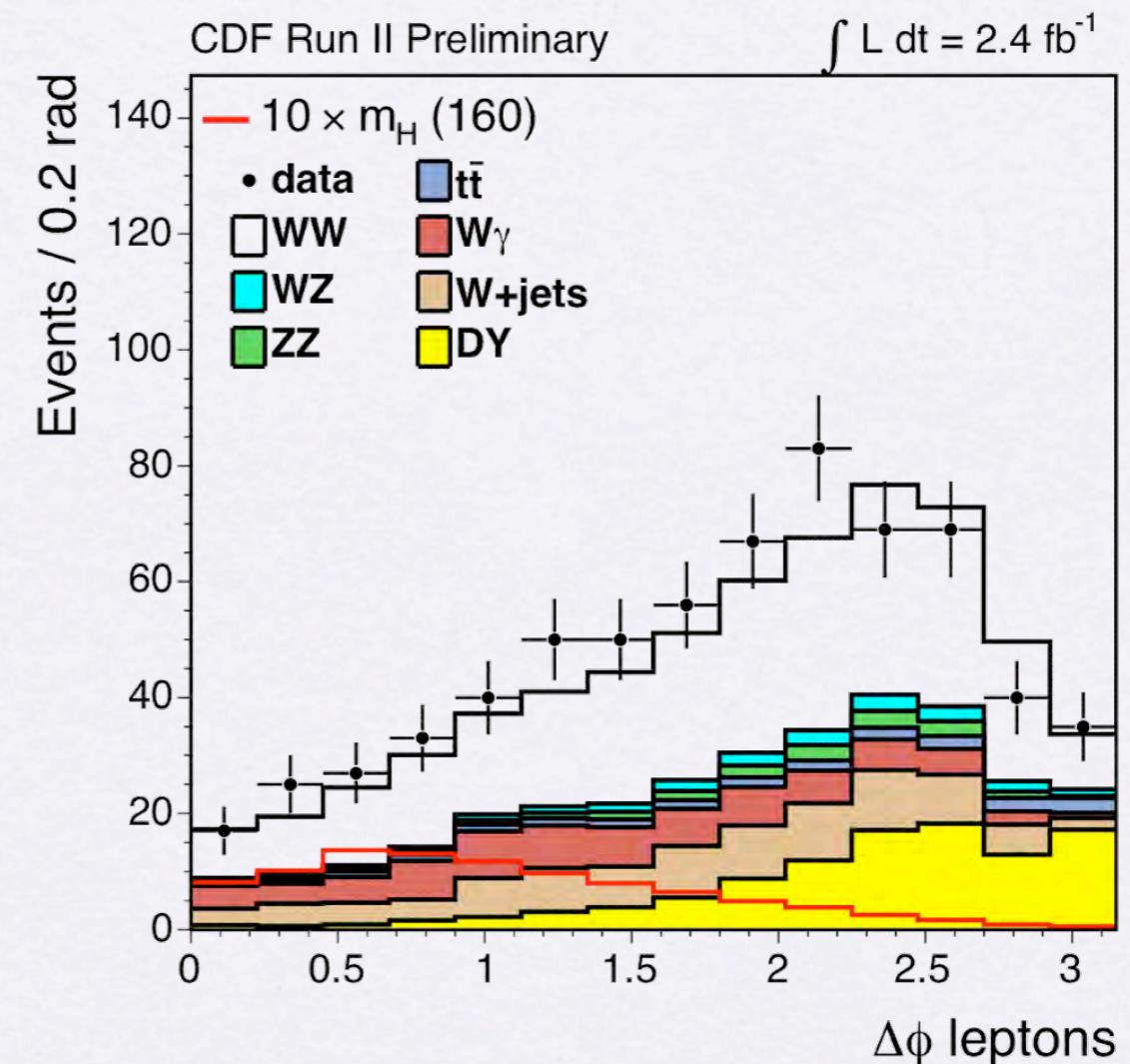
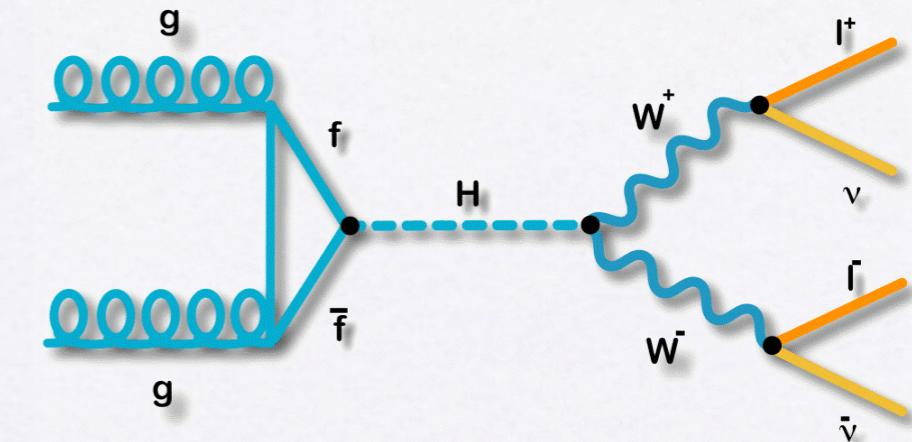
Three main channels (ee, e μ , $\mu\mu$)

- two high p_T isolated leptons
- large missing E_T
- < 2 jets

Higgs mass cannot be reconstructed
(escaping ν 's)

WW^* is irreducible background

- separate using angular correlation
 - Higgs (scalar): small $\Delta\varphi(\ell, \ell')$
 - WW^* (vector): large $\Delta\varphi(\ell, \ell')$



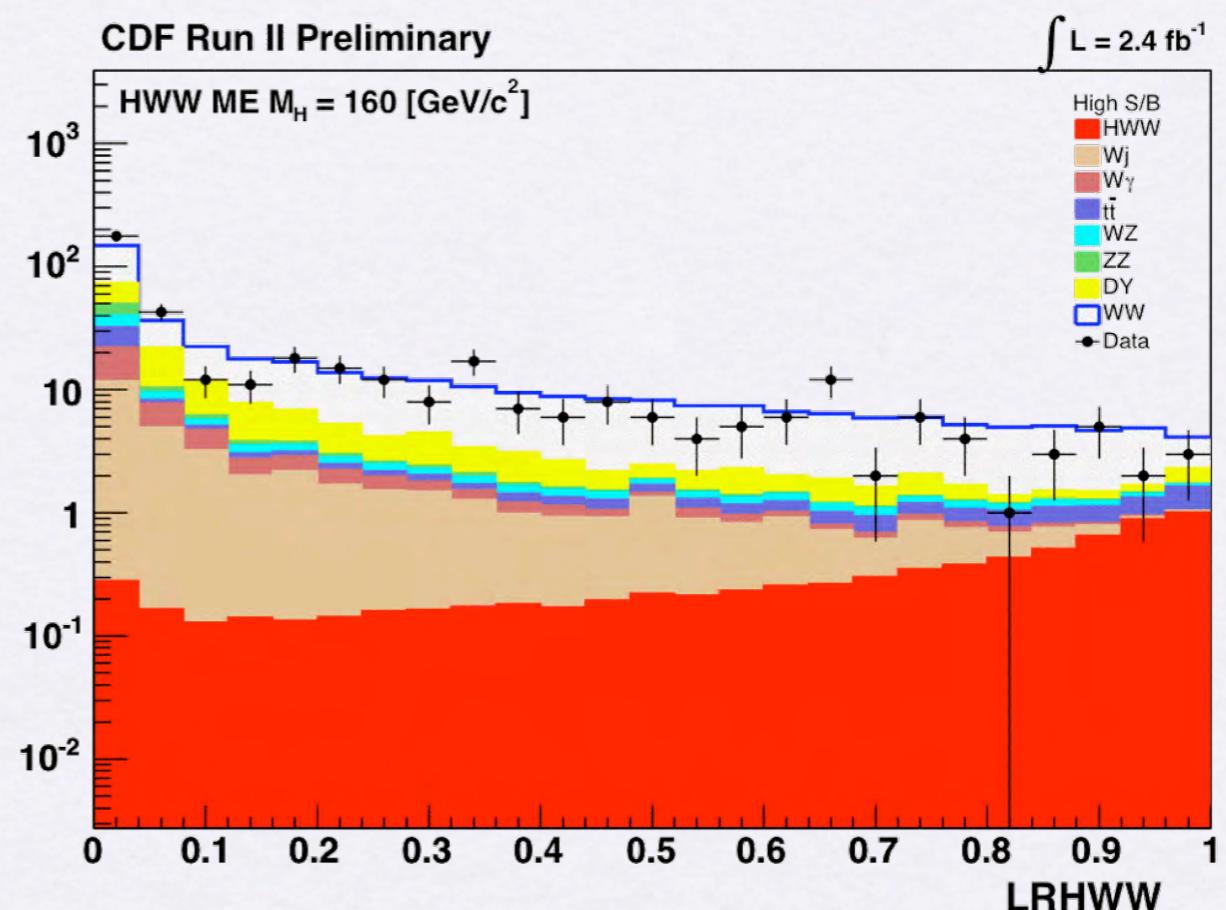
H \rightarrow WW* – Matrix Elements

Matrix elements used to calculate probability that observed event comes from a given parton state using the observed leptons and missing ET

$$\underbrace{\frac{d\sigma}{d\vec{x}}}_{\text{Detector level differential cross section}} \propto \int \underbrace{\frac{f(q_1)}{q_1} \frac{f(q_2)}{q_2} dq_1 dq_2}_{\text{CTEQ6 LO Parton distribution functions}} \times \underbrace{|\mathcal{M}(\vec{y})|^2 d\Phi(\vec{y})}_{\text{Leading order matrix elements from MCFM times phase space factor}} \times \underbrace{W(\vec{y}|\vec{x})}_{\text{Probability density for parton event } \mathbf{y} \text{ given measured event } \mathbf{x}}$$

Calculate likelihood ratio that the event is a Higgs event

$$LR(x_{obs}) \equiv \frac{P_H(x_{obs})}{P_H(x_{obs}) + \sum_i k_i P_i(x_{obs})}$$



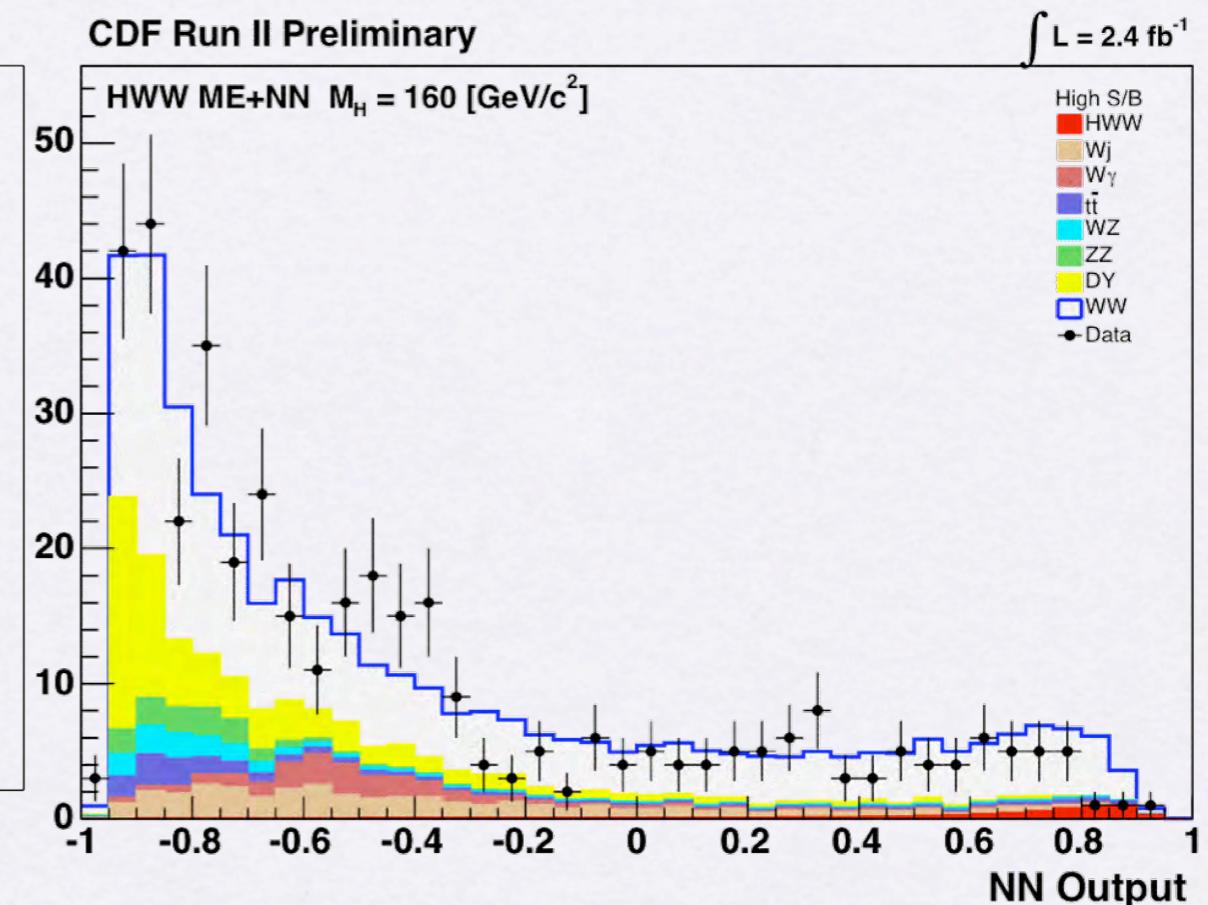
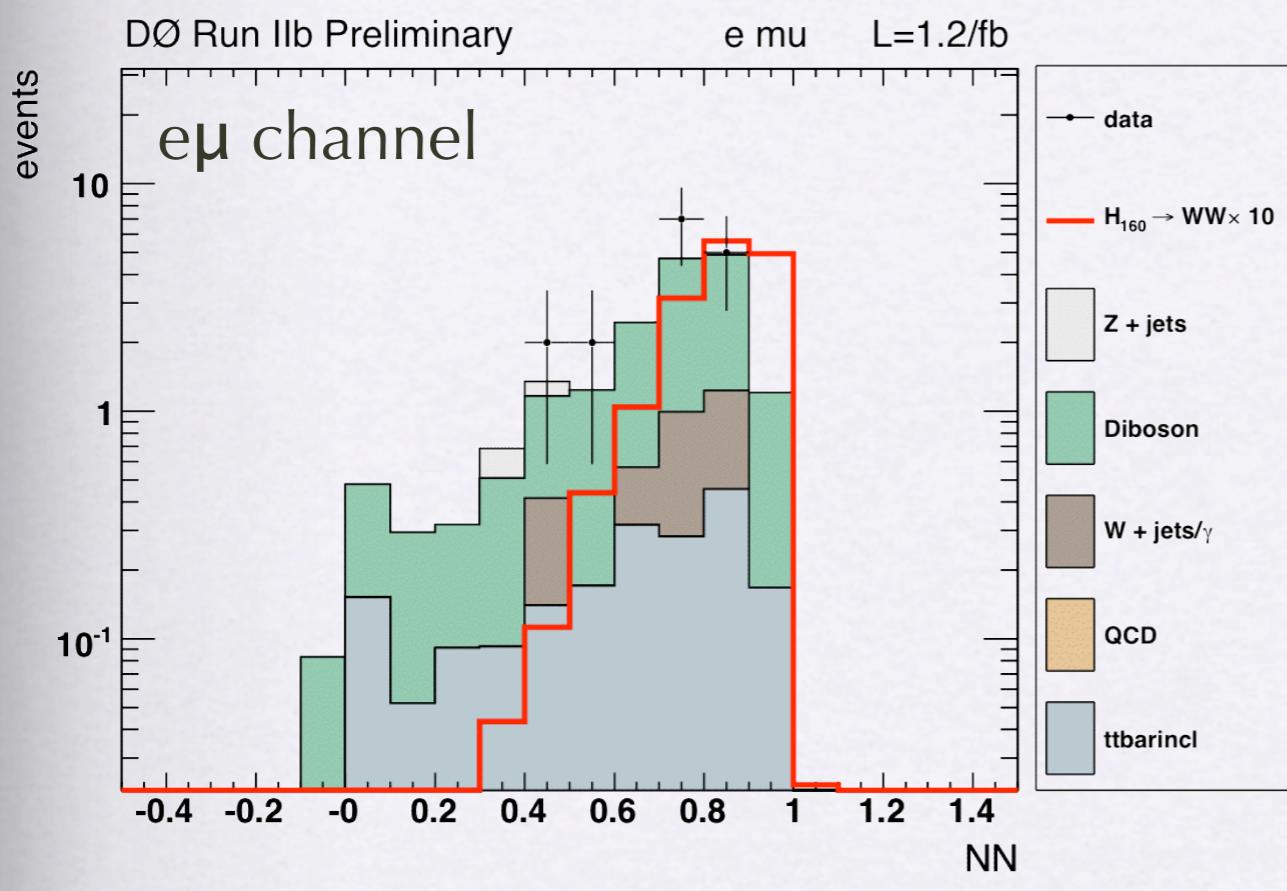
$$H \rightarrow WW^* \rightarrow \ell\nu\ell'\nu'$$

new

Final discriminant based on NN

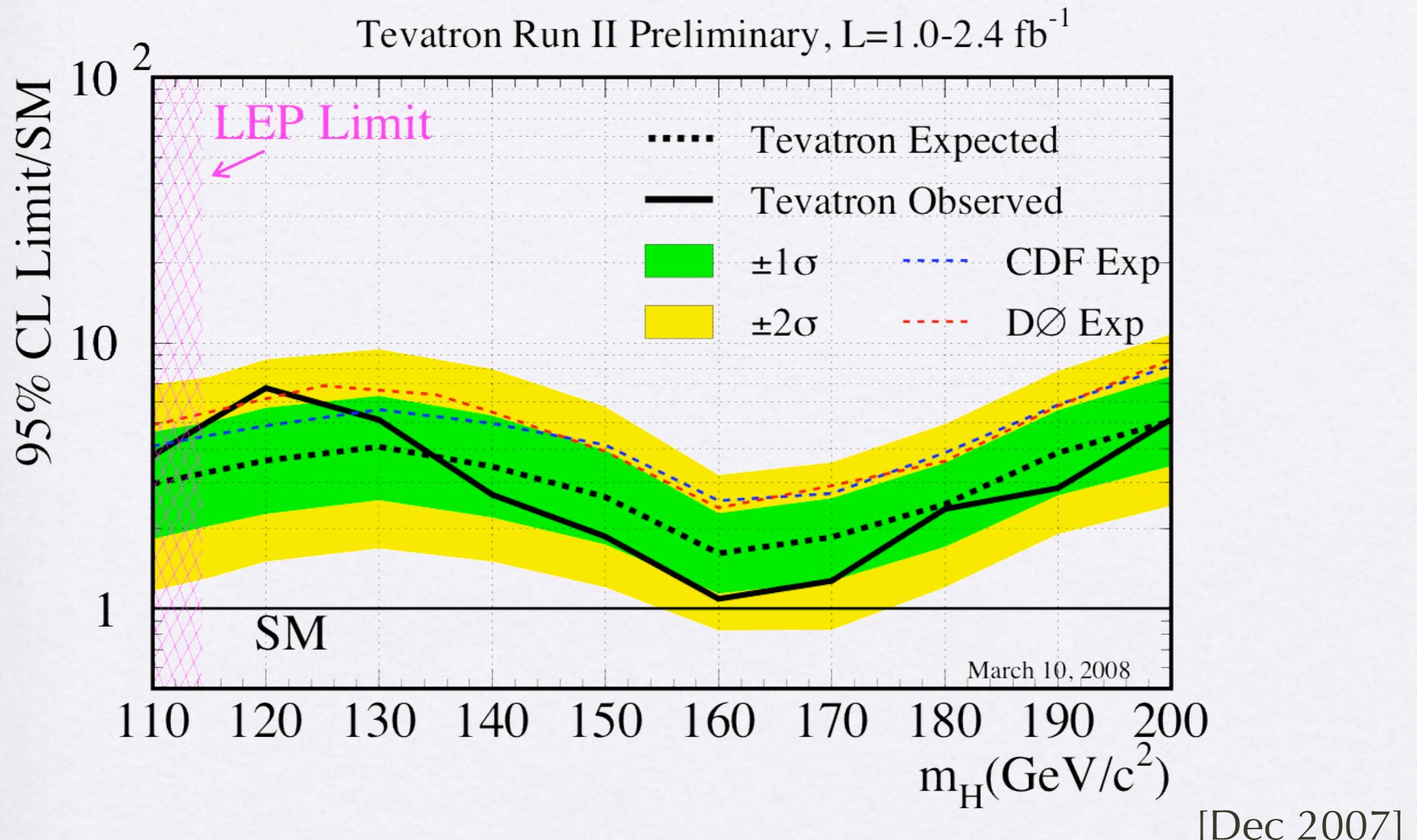
- Likelihood Ratio from Matrix Element calculation
- kinematic & angular variables

$\mathcal{L} (\text{fb}^{-1}) \text{ CL}_{95}/\text{SM } m_H=160 \text{ GeV}$		
	2.4	1.6 (obs) / 2.4 (exp)
	2.3	2.1 (obs) / 2.4 (exp)



Tevatron Combination

new



- for $m_H=115$, obs. (exp.) 95% CL relative to $\sigma_{\text{SM}} = 5.1$ (3.3) [6.2 (4.3)]
- for $m_H=160$, obs. (exp.) 95% CL relative to $\sigma_{\text{SM}} = 1.1$ (1.6) [1.4 (1.9)]

Conclusions

Searching for SM Higgs boson in the mass range 115 – 200 GeV

- approaching SM prediction for $m_H = 160$ GeV

New results shown use $\sim 2 \text{ fb}^{-1}$ data per experiment

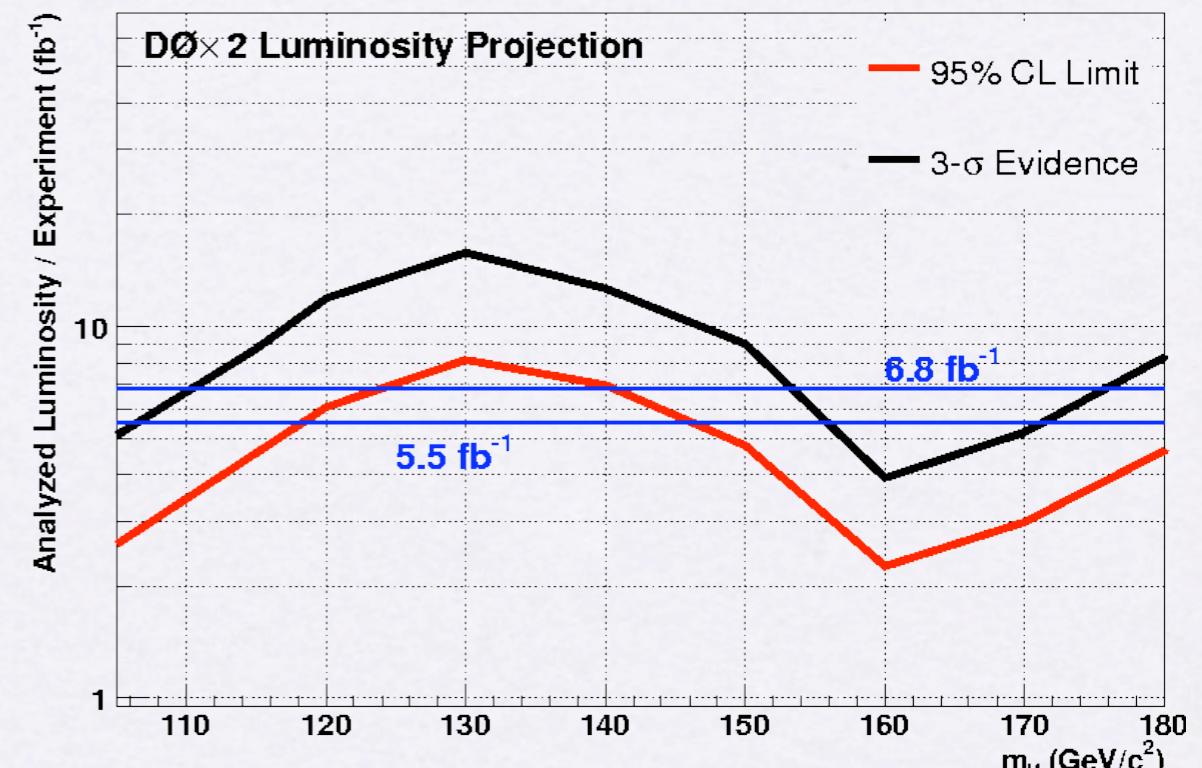
- an additional $> 1 \text{ fb}^{-1}$ on tape
- expect $6 - 8 \text{ fb}^{-1}$ at end of Tevatron operations

In many channels, limits improve linearly with luminosity

- improved detector understanding
- advanced analysis techniques
- adding channels (τ final states)

More details on each analysis:

- CDF: <http://www-cdf.fnal.gov/physics/new/hdg/hdg.html>
- DØ: <http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm>

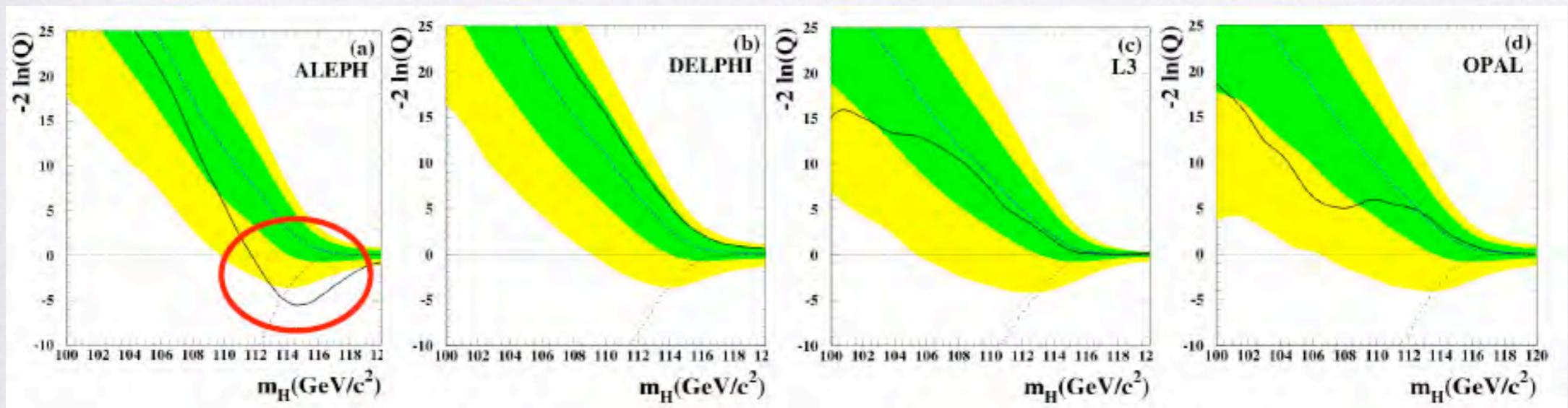
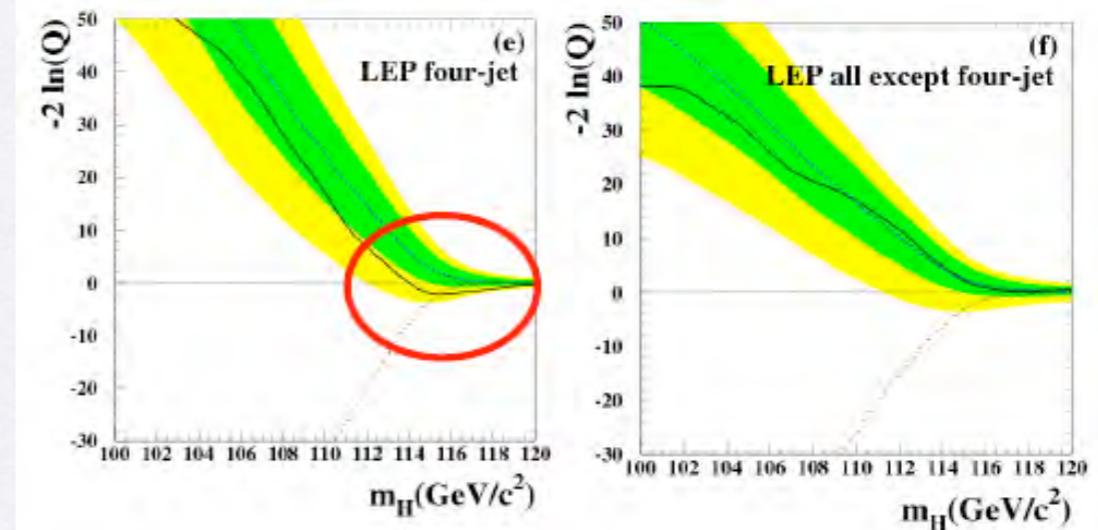


Backup Slides

LEP's Legacy

The effect is mainly due to

- four-jet channel
- ALEPH events



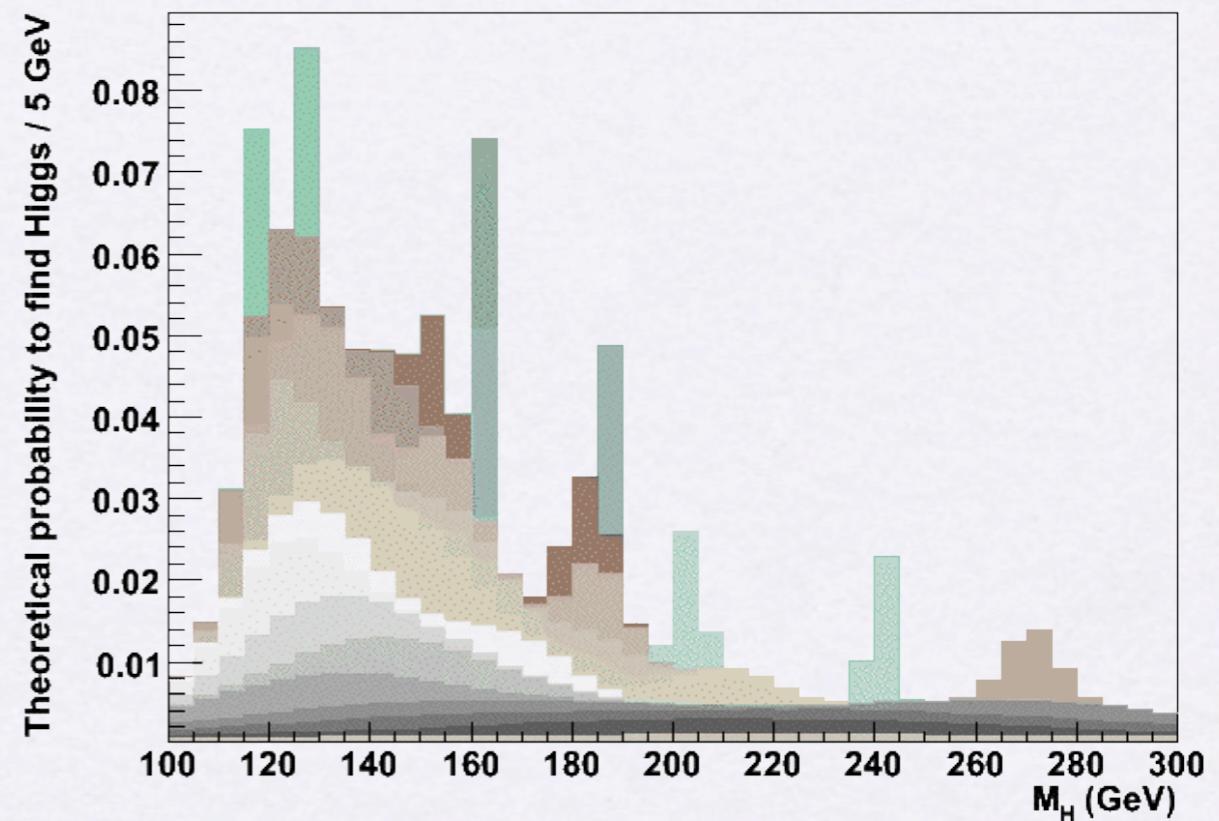
Any Better Prediction?

Higgs mass can't be predicted within SM – no SM parameter relation can be stable under renormalization

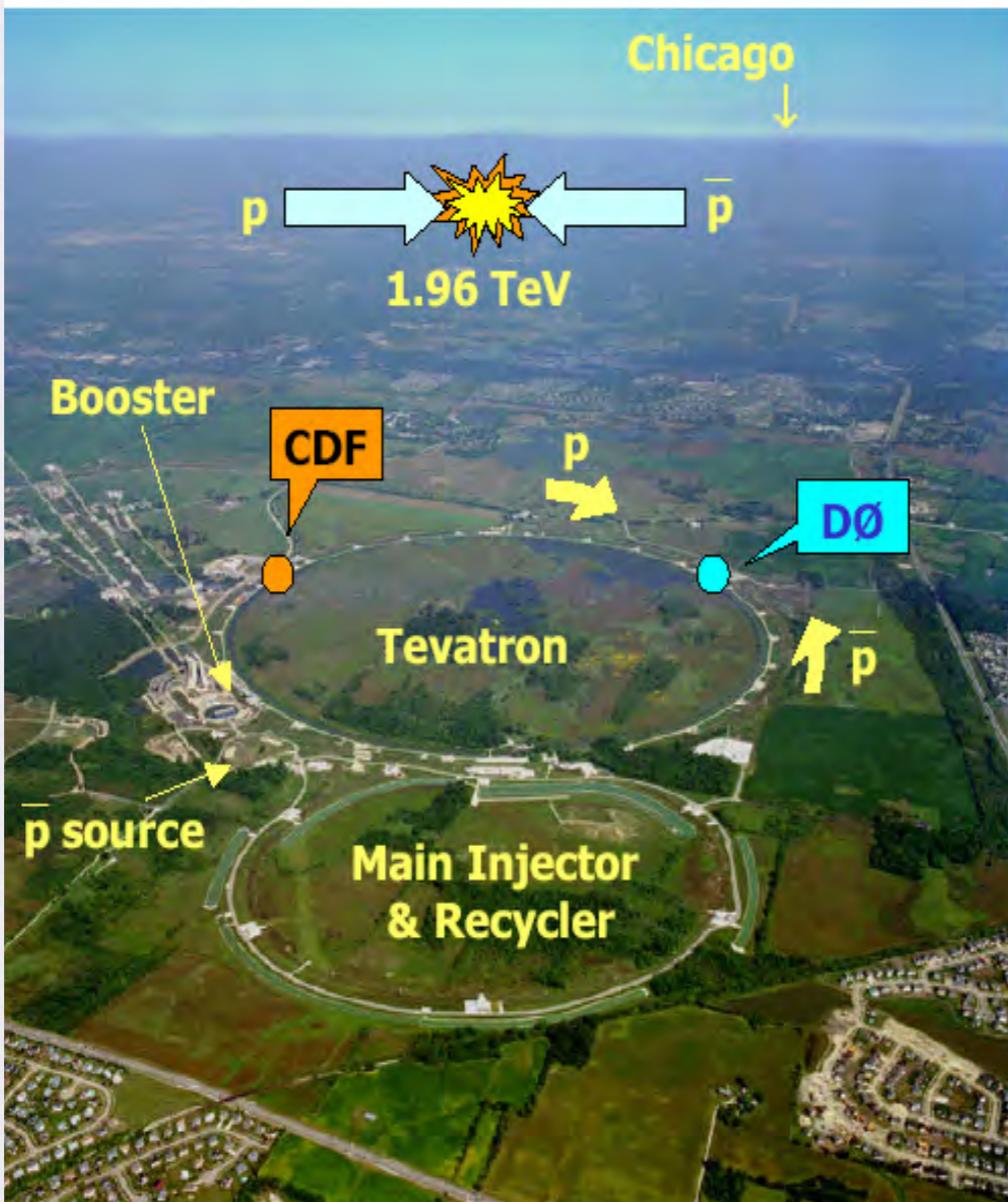
- Iliopoulos, hep-ph 0603146

T. Schücker collected 51 predictions (arXiv:0708.3344)

- Higgs mass is
161.8033989 GeV
 - El Naschie, Chaos Sol.
& Frac. 23 (2005) 739
- Higgs mass is 10^{18} GeV
 - Batakis & Kehagias,
Phys. Lett. B253 (1991) 149



Tevatron at Fermilab



Proton-antiproton collider

- 1.96 TeV energy
- High energy frontier

6.3 km circumference

- 36 (filled) bunches
- 396 ns spacing

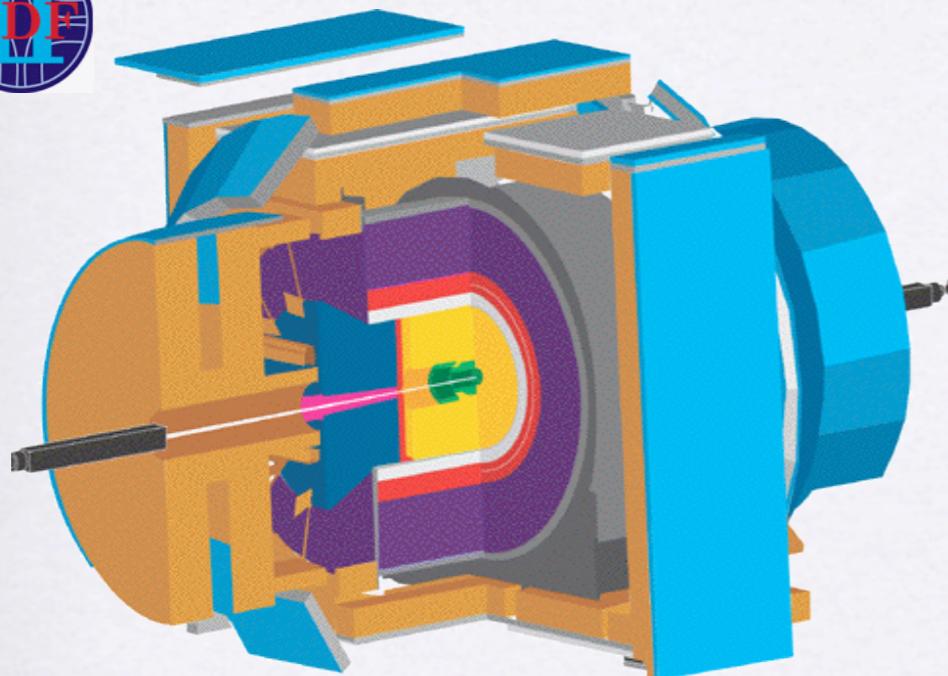
Super-conducting magnets

- 4.2 T dipole field

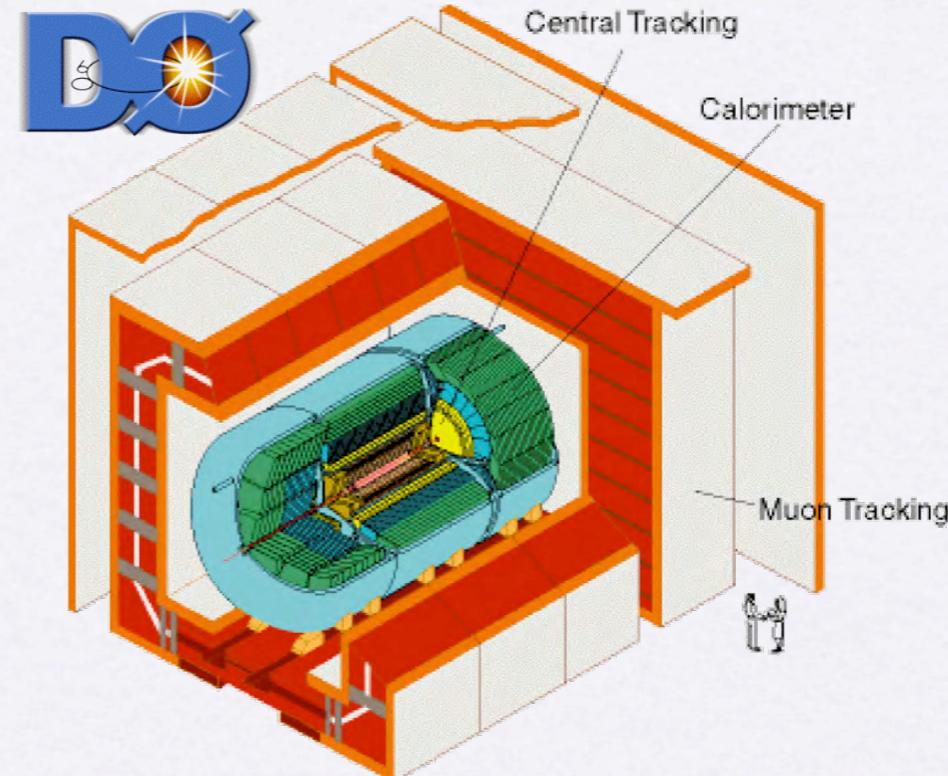
World record luminosity

- $287.8 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$

Detectors



good impact parameter resolution
displaced track triggers
 μ trigger to $|\eta| < 1.1$
particle ID with dE/dx , ToF
 μ trigger to $|\eta| < 2.0$

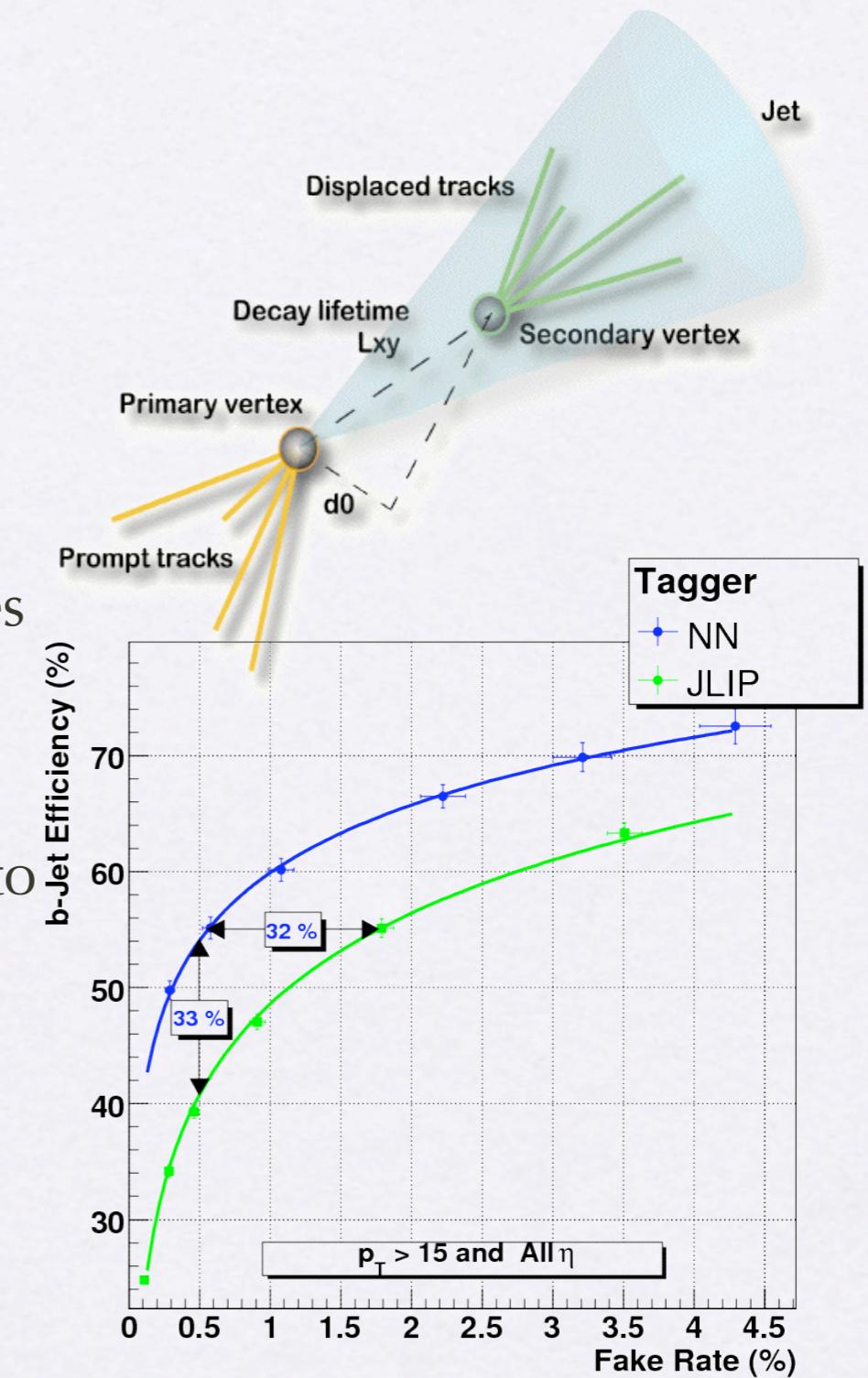


track trigger to $|\eta| < 1.7$
high μ purity
good electron ID

b-tagging

Neural Network b-tagging combines

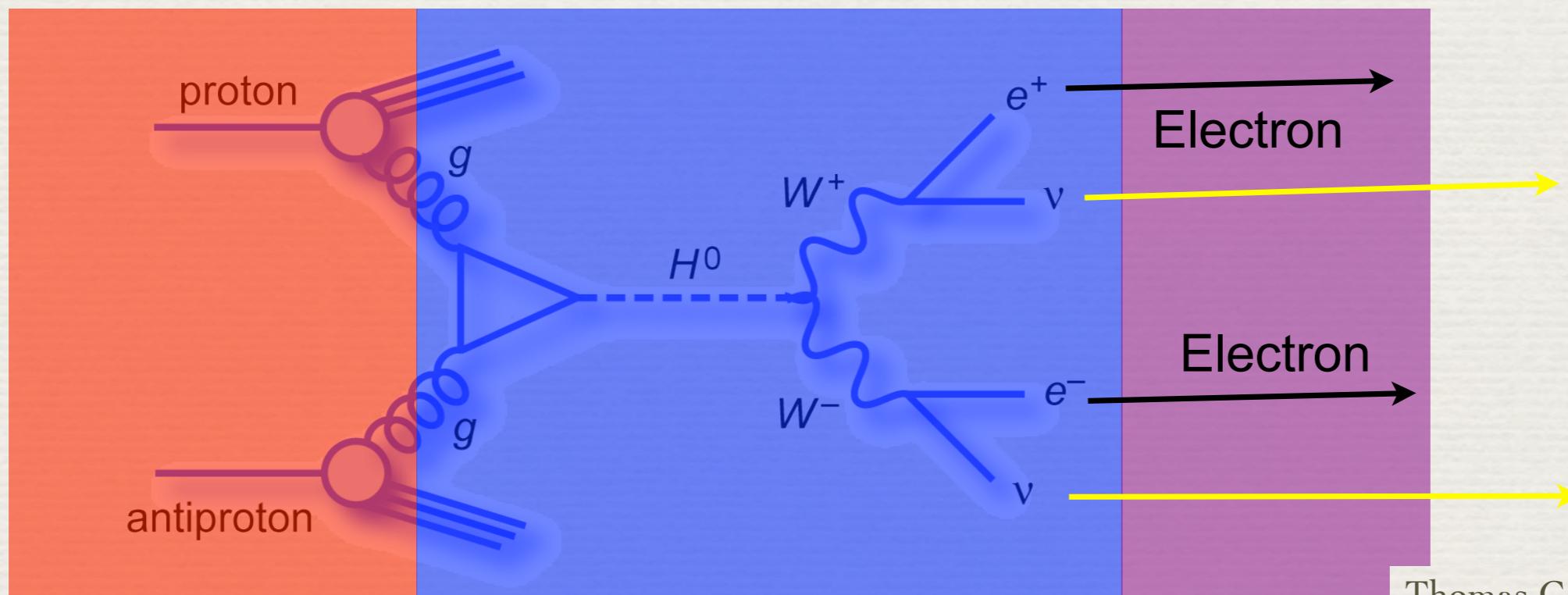
- Counting Signed Impact Parameter
 - Simple counting algorithm
- Jet Lifetime Impact Parameter (JLIP)
 - Fit impact parameter resolution
 - Derive probability that the jet originates from the primary vertex
- Secondary Vertex Tagger
 - Fit tracks with large impact parameter to secondary vertices
- High efficiency and purity
 - Loose: 70% eff., 4.5% mistag
 - Tight: 50% eff., 0.3% mistag



Matrix Element Analysis

Mathematically, the probability density is written as (ignoring 2π 's)

$$\underbrace{\frac{d\sigma}{d\vec{x}}}_{\text{Detector level differential cross section}} \propto \underbrace{\int \frac{f(q_1)}{q_1} \frac{f(q_2)}{q_2} dq_1 dq_2}_{\text{CTEQ6 LO Parton distribution functions}} \times \underbrace{|\mathcal{M}(\vec{y})|^2 d\Phi(\vec{y})}_{\text{Leading order matrix elements from MCFM times phase space factor}} \times \underbrace{W(\vec{y}|\vec{x})}_{\text{Probability density for parton event } \mathbf{y} \text{ given measured event } \mathbf{x}}$$



Thomas Gadfort